GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[XX] ORIGINAL [ ] REVISION NO. ______

Project No. E-25-A08 R6059-0A8 GTRC/GIT DATE 2 / 25/86

Project Director: Sam V. Shelton School/Lab ME

Sponsor: Georgia Power Company 333 Piedmont Avenue
P.O. Box 4545 Atlanta, Georgia 30302

Type Agreement: Letter of Acceptance Dated 1/22/86-TASK RP3 (BOA #95)

Award Period: From 1/1/86 To 6/30/86 (Performance) 6/30/86 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 19,821.00	$ 19,821.00
Funded:	$ 19,821.00	$ 19,821.00

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Experimental Variable Speed Compression Study

ADMINISTRATIVE DATA

OCA Contact R. Dennis Farmer X4820

1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:

Gary L. Birdwell
Georgia Power Company
333 Piedmont Avenue, N.E. (20th Floor)
Atlanta, Georgia 30308
(404) 526-6526

Defense Priority Rating: N/A Military Security Classification: UNCLASSIFIED
(or) Company/Industrial Proprietary: Non-Disclosure Agreement

RESTRICTIONS

See Attached ______ Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor

COMMENTS:

FEB 1986 RECEIVED SUPPORT SERVICES OCA

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SPONSOR'S I. D. NO. 02.256.000.86.011

Project Director	Procurement/GTRI Supply Services	GTRC
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Accounting	Research Communications (2)	Other Jones/Legal/Meye

FORM OCA 65:285

GEORGIA INSTITUTE OF TECHNOLOGY | OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3-19-87

Project No. E-25-A08 School/~~Lab~~ ME

Includes Subproject No.(s) N/A

Project Director(s) Sam V. Shelton GTRC / ~~GIT~~

Sponsor Georgia Power Company - 333 Piedmont Avenue- P.O. Box 4545, Atlanta, Georgia 30302

Title Experimental Variable Speed Compression Study

Effective Completion Date: 6/30/86 (Performance) 6/30/86 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [x] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. ______ Continued by Project No. ______

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Other Duane H.
Russ Embry
Angela Dubose

FORM OCA 69.285

E-25-A08

EXPERIMENTAL VARIABLE-SPEED COMPRESSOR STUDY

FINAL REPORT

To

Georgia Power Company
Technology Development Center
Atlanta, Georgia

By

Sam V. Shelton, PhD
The George W. Woodruff
School of Mechancal Engineering
Atlanta, Georgia 30332

Under

Basic Ordering Agreement (BOA) 95
Task RP3

April 1986

I. BACKGROUND

During the summer of 1985, a Basic Ordering Agreement was negotiated between Georgia Power Company and Georgia Institute of Technology under which specific research tasks could be carried out by Georgia Tech to advance the technology, and knowledge, of residential electric heat pumps.

One purpose of this project was to improve the performance and/or reduce the installed cost of residential heat pumps in the service region of Georgia Power Company.

Space heating and cooling equipment is becoming increasingly regional in nature. This is due to: 1) higher efficiency heat pumps being more weather sensitive; 2) the nature of housing construction, as well as attitudes of builders, varying across the country; and 3) alternative fuels varying in competitiveness in different service areas. In short, the national average heat pump is being found to fall short in meeting everyone's needs across the country.

Competition from alternative heating technologies is also increasing, and imported heat pumps from Japan are on the near horizon. The impact of these technologies on the Georgia Power system is unknown at this time.

While small improvements in heat pumps can still be made in many areas, such as larger air coils and more efficient fan motors, the quantum improvements in electric heat pumps was felt to lie in two areas, i.e.: 1) inverter-driven compressors for capacity modulation, and 2) a triple-integrated heat pump to incorporate heat pump water heating which would reduce equipment and installation cost in multi-family housing.

II. OVERVIEW

Several tasks were funded in three-month increments with funding being terminated before any were completed. Tasks which were initiated under this program are as follows.

A. Variable-Speed-Drive Heat Pumps

Variable-speed residential heat pumps and air conditioners have been discussed and analyzed over the past 10 years. Their energy savings over conventional constant speed systems has been estimated at 10% to 40%, depending on assumptions and models taken.

A major advantage of variable-speed heat pumps which is often overlooked is comfort. Some of these comfort advantages are: 1) room temperature fluctuations are reduced, 2) time to bring the room temperature to the set point at start-up is reduced, 3) air discharge temperatures start-up is reduced, 3) air discharge temperatures at low ambient temperatures are increased, and 4) defrosting time (when the heat pump's heating output is zero) is reduced.

Three projects were related to determining the real world potential improvements possible with variable-speed-drive heat pumps and the hardware necessary to attain that improvement. These are as follows:

1. Analysis & Simulation of Variable-Speed-Drive Heat Pumps

Before hardware can be designed and tested, an analytical model must be developed for the hardware to carry out studies of alternate designs. When possible, as it is in this case, the studies are much less expensive than experimental testing of a large number of different designs. Once the "best" designs have been determined, experimental verification can then be carried out on a few of the designs.

This project was carried out by Drs. Bill Wepfer and Shelton Jeter. It studied variable-speed compressor heat pumps and compared the seasonal performance with the present state-of-the-art constant speed heat pumps. Variable-speed fans were also incorporated to determine their benefit. Results from this task are reported on separately by Drs. Wepfer and Jeter.

2. Experimental Variable-Speed Compressor Study

A simulation model of a heat pump is only as good as the experimental performance data available for the components of the system. Good reliable data is available for all components in a variable-speed heat pump (such as fans and air coils) except the variable-frequency inverter and compressor. The total system performance is acutely dependent on these two components.

Therefore, this task was to build a small refrigerant test loop in which various variable-speed compressors could be tested. Other components could also be tested in the facility.

Three different type compressors and inverters were to be tested under varying loads and speeds. This was to provide all data necessary for input to the simulation model to predict the total heat pump seasonal performance. Various control strategies were also to be simulated to determine the optimum control of the variable-speed compressor. This task was being carried out by Dr. Sam Shelton and is discussed in detail in Section III below.

B. Triple-Integrated Heat Pump Controls

The triple-integrated heat pump being developed by E-Tech, Inc., provides unique problems, and opportunities, for control of the multi-function heat pump. The unit has several modes not found in conventional heat pumps, such as dehumidification and ventilation. Present solid state technology is the best means to reliably control these modes.

Expertise in this solid state control area is being used in this task to develop such a control package. Close coordination was being maintained with E-Tech, Inc., in this project to meet their needs.

This task is being carried out by Dr. Roger Webb and Ms. Gail Wells, with assistance from Dr. Sam Shelton in developing the truth table. The truth table is given in Appendix A.

C. Japanese Heat Pumps

Inverter technology has now been developed to the point where 40% of electric heat pumps sold in Japan in 1985 were variable-speed, inverter-equipped. None were available in the U.S. by any manufacturer.

In order to assess this existing technology and learn from it, procurement of two 3-ton heat pump units from Japan was to be initiated. These units were to be examined and a test program developed to determine their design technology and determine their performance.

Since the Japanese are presently starting to set up distribution of heat pumps in the U.S., this was to provide information regarding these units versus U.S. units and help Georgia Power develop knowledge regarding them before they started being installed on their system. Procurement of these units was not completed before being terminated by Georgia Power.

The two units which are desired are as follows:

1. Hitachi Inverter "Q" Model Space Heating Heat Pump
   Model Number: RCI-100A2 Outdoor Compressor Unit
   with RCI-100HT3 Indoor Coil Unit

2. Toshiba Inverter Space Heating Heat Pump
   Model Number: RAS-M456EAV Outdoor Compressor Unit
   with RAS-M286EV(W) Indoor Coil Unit

The agent in Japan which was to have purchased and shipped these units is:

Mr. Fouad Debs
A. Debs and Company, Ltd.
P. O. Box Central 268
Osaka, Japan

A letter to Mr. Debs requesting pricing before shipment is attached as Appendix B. No reply was received.

III. EXPERIMENTAL VARIABLE-SPEED COMPRESSOR STUDY TASK

A. Introduction

Some of the factors determining the performance of inverter-driven compressors and which vary with speed and pressure ratio are:

1. Cylinder/gas heat transfer
2. Bearing friction
3. Valve pressure losses
4. Electric motor efficiency
5. Inverter efficiency

Other than the electric motor and inverter electrical efficiency, these factors are difficult to individually determine. However, this detailed information about the compressor is not needed for system performance calculations. Only the overall compressor isotropic efficiency, power input, and refrigerant flow rate is required at each speed and pressure ratio.

This task was to experimentally deterine 1) combined inverter/motor efficiency, 2) compressor isotropic efficiency, 3) shaft input power, and 4) refrigerant flow rate with varying compressor speed and condenser/evaporator pressure ratio.

These measurements were to be carried out on three different compressors which were appropriate candidates for capacity-modulated unitary residential heat pumps as well as triple-integrated heat pumps under development.

This data was then to be used in the heat pump model developed under BOA 95 - Task RP1 for variable-speed-drive heat pumps to compare new inverter/compressor technology and to more realistically predict the potential performance and savings of variable-speed-drive heat pumps than is presently possible.

These measurements were to be carried out by construction of a general purpose refrigerant test loop. This test loop was to be constructed such that the compressor, condenser, evaporator, and expansion valve components could easily be removed and new components installed for testing. The loop was initially to use a water-cooled condenser and water-chiller evaporator with controls to maintain any desired condenser and evaporator pressures for compressor testing.

The loop was to be comprehensively instrumented with refrigerant flow meters, pressure transducers, and temperature instrumentation. In addition, the hermitically sealed compressors were to be opened and internal instrumentation installed to measure torque and speed between the motor and compressor.

Analog instrumentation was to be interfaced with a micro-computer data acquisition system. This system would digitize the signals and analyze the data in real time. It would display, print, and store magnetically for further study and analysis.

The refrigeration test loop, instrumentation, and data acquisition system was to serve as a test bed for future heat pump component testing such as digitally-controlled expansion valves and variable-fan-speed evaporators and condensers.

B. Subtasks Description

The experimental variable-speed compressor study described above was expected to be a 12-month program with six subtasks. These were: 1) Refrigeration Test Loop Design, 2) Instrumentation Design, 3) Test Compressors Selection and Instrumentation, 4) Test Loop Construction, 5) Compressor Testing, and 6) Heat Pump Model Performance Calculations. Only the first three subtasks starting 1 January and ending 31 March 1986 were funded. These initial tasks are described as follows:

1. Refrigeration Test Loop Design

The refrigeration loop was to be made up of a test compressor, water-chiller evaporator, water-cooled condenser, and expansion valve. The loop was to be designed with appropriate receivers and controls to maintain desired condenser and evaporator pressure as well as evaporator leaving superheat. Components would be properly sized and hardware selected.

2. Instrumentation Design

An instrumentation system was to be design and components selected. This included pressure transducers, thermocouples, flow meters, and electrical power measuring transducers. In addition, electric motor torque and speed transducers were to be selected. All system transducers were to be interfaced with a micro-computer data acquisition system which would be capable of reading values and calculating desired system performance parameters. This information would be logged on a printer and magnetic disk, as well as displayed on a monitor. This instrumentation system, at a cost of approximately $11,500, was expected to be supplied by Georgia Power Company outside this task.

3. Test Compressors Selection and Instrumentation

Current inverter-driven compressor technology was to be surveyed and major U.S. and Japanese compressor manufacturers contacted for specific information regarding possible inverter-driven compressors to be obtained for testing. At least two were to be selected which were suitable for residential unitary heat pumps and triple-integrated heat pumps.

C. Test Loop Design

In accordance with the task work statement submitted in original project proposal, the refrigerant test loop composed of a test compressor, water chiller evaporator, water cooled condenser, and expansion valve was designed (see refrigerant loop drawing) and components selected.

Necessary temperature, pressure, flow, and electrical power instrumentation has been selected and incorporated in the designed loop.

An instrument list including temperature, pressure, and flow instrumentaion was put together with vendor part numbers and rough cost estimates. Suction, discharge, and liquid line pipe sizing was developed.

A basic support structure was designed and built. This structure will support the refrigerent test loop components, the various instrumentation, and all piping.

A schematic showing the refrigerant test loop design is shown in Figure 1, with pipe sizing shown in Figure 2. All piping is sized to result in less than a 1 psi drop in pressure. Table 1 shows the components selected for procuement with the estimated cost and source for each.

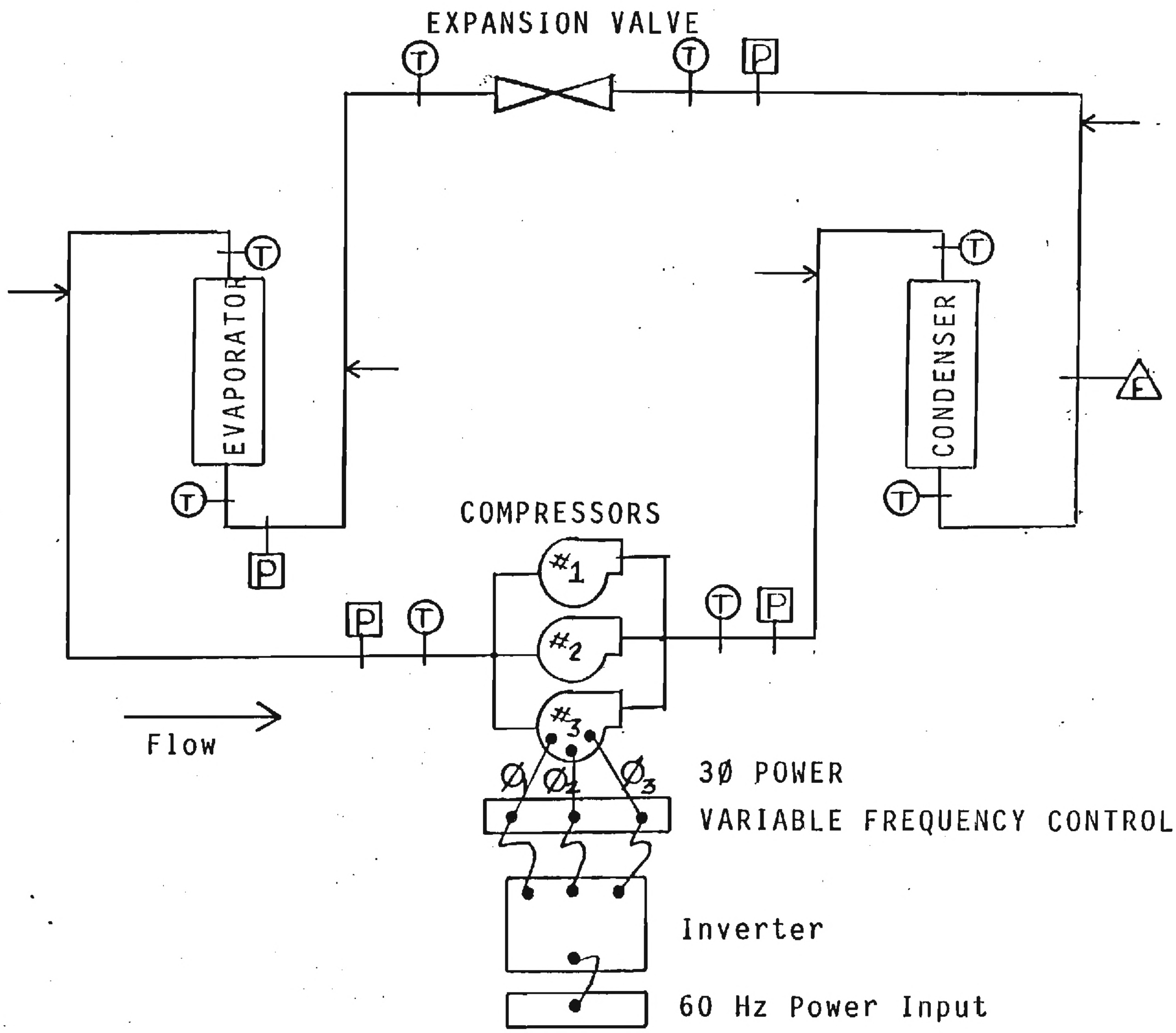


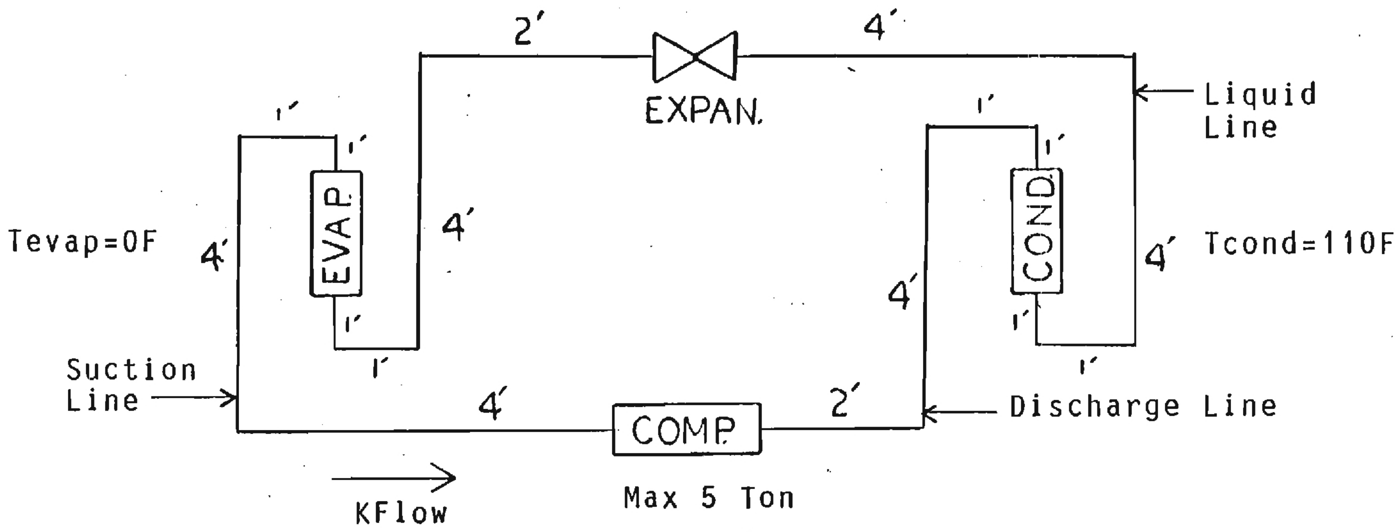
FIGURE 1: REFRIGERATION TEST LOOP

TRANSDUCERS

T - Temperature

P - Pressure

F Flow



LINE SIZES

Suction Line--------1 1/8 Dia. (O.D.)
Discharge Line------ 5/8 Dia. (O.D.)
Liquid Line--------- 1/2 Dia. (O.D.)

FIGURE 2: PIPE SIZING DIAGRAM

TABLE 1
INSTRUMENT LIST

PART	PART DESCRIPTION	PART NO.	QTY.	ESTIMATED TOTAL $	SUPPLIER
Thermocouple	6" Chromel - Alumel Thermocouple (Type K)	CASS-18G-6	10	$ 270.00 ($27 ea.)	Omega
Test Plugs	Self-Sealing Temperature Test Plugs	OPNE-12	10	$ 155.00 ($15.50 ea.)	Omega
Thermocouple Wire	100' Chromel - Alumel Thermocouple Wire (Type K)	304-K-MO-062-100	100'	$ 125.00	Omega
Flowmeter	Turbine Flowmeter	FTB-201	1	$1050.00	Omega
Flowmeter Installation Kit	Flowmeter Installation Kit	FTB-K3	1	$ 120.00	Omega
Integral Signal Conditioner	Integral Signal Conditioner for Flowmeter	FLSC-51	1	$ 318.50	Omega
Pressure Transducer	Series 303 Pressure Transducer (0-300 psig) Barksdale	303-H2-07CG-09-0	4	$1200.00 ($300 ea)	Transamerica Delaval (Barksdale)
Water-Cooled Condenser Coil	5-ton Water-cooled Condenser Coil	--	1	$ 200.00	E-Tech
Water-Chiller Evaporator Coil	5-ton Water-Chiller Evaporator Coil	--	1	$ 200.00	E-Tech
Copper Piping	20' of 1/2" OD Copper Pipe - Type L		as specified	$ 250.00	Graves Refrigeration
	20' of 5/8" OD Copper Pipe - Type L		" "		" "
	20' of 1-1/8" OD Copper Pipe - Type L		" "		" "

TABLE 1, INSTRUMENT LIST, PAGE 2

PART	PART DESCRIPTION	PART NO.	QTY.	ESTIMATED TOTAL $	SUPPLIER
Pipe Insulation	6' Length of 1/2" ID Copper Pipe Insulation		4		Graves Refrigeration
	6' Length of 5/8" ID Copper Pipe Insulation		4	$ 300.00	" "
	6' Length of 1-1/8" ID Copper Pipe Insulation		4		" "
R22	30 lb. Disposable Can of R22 (Refrigerant 22)		30 lb.	$ 60.00	Graves Refrigeration
Expansion Valve	Expansion Valve (5-ton)		1	$ 25.00	Georgia Valve & Fitting
Swagelock	1/2" OD x 1/2" NPT Female Run Tee	B-810-3-8TFT	4		Georgia Valve & Fitting
Valves,	1/2" OD Union Elbow	B-810-9	2		" " "
Fittings,	5/8" OD Union Elbow	B-1010-9	1		" " "
&	1/2" Union Tee	B-810-3	2	$ 85.00	" " "
Connectors	5/8" Union Tee	B-1010-3	3		" " "
"	1/2" OD x 1/2" NPT Fractional Tube Adapt. to Fem. Pipe	B-8-TA-7-8	2		" " "
	5/8" OD x 1/2" NPT Fractional Tube Adapt. to Fem. Pipe	B-10-TA-7-8	3		" " "
Data Gatherer	Data Acquisition System	Isaac 91I	1	$5000.00+	Cyborg
Watt Meters	1ϕ watt meters	--	1	$ 60.00	
	2ϕ watt meters	--	1	$ 200.00	
Compressor	3 various types		3	$1500.00 ($500 ea.)	

TOTAL ESTIMATED PRICE FOR PARTS:	$11,118.50
TOOL SET FOR PIPING CONSTRUCTION & TESTING:	$ 500.00
TOTAL ESTIMATED COST:	$11,618.50

LIST OF SUPPLIERS

Cyborg Corp.
55 Chapel Street
Newton, MA 02158
(800)343-4494

E-Tech, Inc.
3570 American Drive
Atlanta, GA 30341
(404)458-6643

Georgia Valve & Fitting Co.
P. O. Box 81163
Atlanta, GA 30341
(404)458-8045

Graves Refrigeration, Inc.
457 Todd St.
Atlanta, GA 30312
(404)522-3755

Omega Engineering, Inc.
One Omega Drive
Box 4047
Stamford, CT 06907
(203)359-1660

Transamerica Delaval Inc.
3379 Peachtree Road, NE
Room 260
Atlanta, GA 30326
(404)261-7064

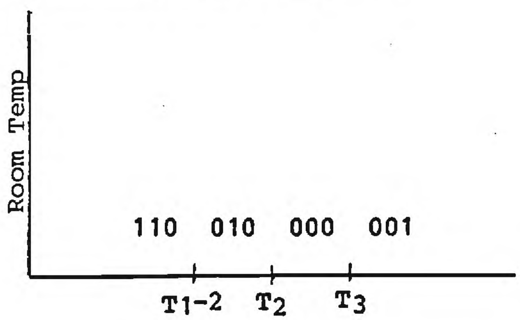
APPENDIX A

TRIPLE INTEGRATED APPLIANCE

CONTROL TRUTH TABLE

FUNCTION	Therm. Pos.	Room Temp.	Humidistat.	Aquastat.	Exhaust	Vent.	Defrost	Compressor	Strip Heat	Blower (inside)	Fan (outside)	Elec. DHW	DHW Pump	Valve 1	Valve 2	Inside Damper	Outside Damper	Defrost
normal heating	11	010	X	X	0	0	0	1	0	1	1	0	0	0	0	1	1	0
low cap. htg.	11	110	X	X	0	0	0	1	1	1	1	0	0	0	0	1	1	0
emerg. heating	10	X10	X	X	0	0	0	0	1	1	0	0	0	0	0	1	1	1
defrost (htg)*	11	X10	X	0	0	0	1	0	1	1	0	0	0	0	0	1	1	1
defrost (DHW)*	X1	XXX	X	1	0	0	1	0	0	0	0	1	1	0	0	1	1	1
DHW (htg)	11	X0X	X	1	0	0	0	1	0	0	1	0	1	1	0	1	1	0
DHW (EH)	10	00X	X	1	0	0	0	0	0	0	0	1	1	X	X	X	X	0
DHW (cool)	01	XX0	X	1	0	0	0	1	0	0	1	0	1	1	0	1	1	0
DHW & Cooling	01	XX1	X	1	0	0	0	1	0	1	1	0	1	1	1	1	1	0
Cooling	01	XX1	X	0	0	0	0	1	0	1	1	0	0	0	1	1	1	0
Dehumid.	00	XXX	1	X	0	0	0	1	0	1	0	0	0	0	1	2	2	0
Exhaust	XX	XXX	X	X	1	0	0	0	0	0	1	0	0	X	X	2	1	0
Ventilation	XX	XXX	X	X	0	1	0	0	0	1	1	0	0	X	X	1	3	0
Off	00	XXX	0	X	0	0	0	0	0	0	0	0	0	X	X	1	1	0

*Timed



Therm. Pos.

Heating	11
Emerg. Htg.	10
Cool	01
Off	00

APPENDIX B

LETTER TO JAPANESE AGENT

28 October 86

Mr. Fouad Debs
A. Debs and Company, Ltd.
P.O. Box Central 268
Osaka JAPAN

Dear Mr. Debs:

We would like to purchase two residential heat pumps for space heating and cooling which are available in Japan. There are two components associated with each heat pump. One component is the outdoor unit, and the second component is the indoor unit. These units are connected together by piping at the time of installation.

The two heat pump models which are desired are as follows:

1. Hitachi Inverter "Q" Model Space Heating Heat Pump

   Model Number: RCI-100A2 Outdoor Compressor Unit
   with RCI-100HT3 Indoor Coil Unit

2. Toshiba Inverter Space Heating Heat Pump

   Model Number: RAS-M456EAV Outdoor Compressor Unit
   with RAS-M286EV(W) Indoor Coil Unit

We request that you act as agent for us in purchasing and shipping this equipment.

Before the purchase is made, however, please advise us on:

1. estimated cost of the equipment,
2. estimated brokerage/agent fees,
3. estimated air freight shipping cost,
4. estimated time required to purchase and ship,
5. money transfer instructions.

After we receive the information, we will make the proper money transfer arrangements, and approve the purchase and shipping of the equipment.

Respectfully,

Sam V. Shelton

cc: Dr. Atif Debs